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**SURFACE SCATTERING CHARACTERISTICS**  
**AND**  
**THE MEASUREMENT OF PARTICULATE CONTAMINATION**

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**ABSTRACT**

Surface scattering measurement techniques can be adopted for use in spacecraft contamination control programs. A witness mirror measurement program was developed and implemented for the NASA Cosmic Background Explorer (COBE) spacecraft. Scattering measurements were obtained before and after a qualification level vibration test for several COBE prototype instruments. The measurements indicate a significant amount of particle redistribution occurred during the vibration test. This paper summarizes the methodology used and the results obtained from this monitoring program.

**INTRODUCTION**

Contamination deposited on optical surfaces can greatly reduce instrument performance, therefore impairing the achievement of mission scientific goals. Particulates such as fibers, dust or remains of fabrication processes or chemical species, outgassed from a variety of materials or generated during virtually any mission phase and subsequently adsorbed or deposited on critical surfaces, degrade surface characteristics. Among the principal effects of the presence of contaminants are surface obscuration, scattering and absorption of incident radiation, loss of throughput, and increase of surface absorptivity. Particles in the instrument field of view have an obvious negative influence in the process of data collection.

The instruments installed on the Cosmic Background Explorer (COBE), are highly sensitive to contamination. It is therefore very important to keep under control the amount of contamination on all sensitive surfaces. Such an effort must be undertaken from the early fabrication, assembly and testing phases, and continue through all subsequent phases of the COBE mission. All requirements, procedures and monitoring plans necessary to achieve this goal are identified in the COBE Contamination Control Plan (CCP) [1].

The COBE CCP includes the implementation of a contamination monitoring program for the Thermal Structural Unit (TSU). The TSU is a set of prototype instruments which were used for test and demonstration. The COBE instruments are located in an element known as the Cryogenic Optical Assembly (COA). The TSU consisted of a prototype COA which contained a Diffuse Infrared Radiation Experiment (DIRBE) and a prototype Far Infrared Radiation Spectrometer (FIRAS), two of the most contamination-critical instruments on the COBE. Figure 1 depicts the COA with the two instruments. The primary objective of the contamination monitoring program was to monitor the presence of contaminants during all phases of the TSU testing.

This paper describes the results of the initial phase of the program developed to monitor contamination during the vibration test performed on the flight-like TSU integrated COA (Cryogenic Optical Assembly).

The vibration test was conducted March of 1985. The TSU COA was flight-like except there was no contamination cover over the DIRBE baffle aperture.

Prior to test, all TSU COA parts were cleaned to a level 100A per MIL STD 1246A [2], and assembled in a Class 10,000 clean tent. Surface cleanliness measurements taken before transportation to the vibration cell, revealed external COA surfaces to be level 200-300 per MIL STD 1246A. Prior to transport to the vibration test, the TSU was double bagged in cleaned RCAS 2400 bagging material.

The integrated flight-like TSU COA was originally instrumented with 15 contamination witness mirrors. Due to concerns about overstressing two of the DIRBE mirror mounts, two witness mirrors were taken off the TSU prior to the vibration test. The location of the witness mirrors are illustrated in Figure 1.

The contamination witness mirror program consists of performing before and after testing characterization on each witness mirror, including:

- 1)- BRDF characterization;
- 2)- Surface cleanliness determination per ASTM F24-65 standard [3]; and
- 3)- Surface morphology examination by optical microscopy, with photographic documentation.

Bidirectional Reflectance Distribution Function (BRDF) measurement is a particularly interesting technique, as it provides information about the scattering properties of optical surfaces. The DIRBE performance requirement [1] is stated in terms of percent change of mirror BRDF.

BRDF measurements were performed on all witness mirrors before and after the vibration test. The comparison of these data show percent change in BRDF characteristics for the witness mirrors, which were exposed to the same contamination environment as the TSU COA surfaces.

## RESULTS

### BRDF CHARACTERIZATION

A complete description of the BRDF characterization technique adopted in this program is reported in Reference [4].

Each witness mirror was measured before and after the vibration test. In order to obtain a complete description of the mirror characteristics, three areas were measured on each mirror. The BRDF curves obtained for mirrors II, VI, are reported in Figures 2 to 13. In these figures, the curves labeled B1, B2 and B3 are relative to the mirror areas as measured before the vibration test. Analogously, curves A1, A2 and A3 refer to the after vibration test BRDF measurements. As it can be seen from the figures, the after test BRDF values are generally higher than the before test ones. The differences are certainly above the experimental error, and represent, therefore, an effect of the contamination accumulated on the mirrors during the vibration test. In some cases, the contamination effect is strong enough to cause dramatic changes in the BRDF values, up to two orders of magnitude

In general, as already mentioned, the BRDF values obtained in the after test measurements are higher in modulus. Also, the curves tend to level off at high scattering angles, which represents a diffuse scatter component due to the presence of contaminants. In other words, the specular behaviour typical of the clean mirror (straight BRDF line with negative slope), is poisoned by a component typical of a diffuse scatterer, in this case the contaminant particulates.

In Table 1, representative values of the BRDF curves are reported for each witness mirror. The BRDF values obtained at the scattering angles of 30 and 60 degrees on the central areas of each mirror were arbitrarily chosen to be representative comparison data. (curves #2 in the Figures). The percent change of BRDF based on these measurements are also reported in Table 1. It is noteworthy to remember at this time that the current DIRBE requirements allow a maximum of 50% BRDF change due to mirror contamination. The reported BRDF percent changes vary from 8% up to 600%, showing that, in some cases, a very significant amount of contamination occurred during the vibration test.

## SURFACE CLEANLINESS LEVELS

The presence of contamination on the after test mirrors detected by the BRDF measurements is confirmed by the surface cleanliness level data, also reported in Table 1. In most cases, the after test cleanliness levels are higher (higher level of contamination) than the before test levels (which were levels 25-100 on the mirrors). Nine out of the twelve mirrors show an after test cleanliness level higher than the COA cleanliness requirement (level 300).

## OPTICAL MICROSCOPY EXAMINATION

All witness mirrors were examined via optical microscopy to obtain a visual evaluation of the nature and morphology of contaminants and to evaluate the mirror cleanliness levels. Photographical records of contaminants were taken at magnifications varying between 45X and 100X. Cleanliness levels were obtained following the ASTM procedure [3].

In Table 2, the most interesting observed features are reported for each mirror. Fifteen mirrors were planned to be installed in the COBE TSU; Mirrors VII and IX were not installed because of potential stress on mirror mounts. Mirror XIV was not retrieved after the vibration test; it will be removed later in the program.

## SUMMARY AND CONCLUSIONS

The data obtained from the contamination witness mirrors after the TSU COA first vibration test show that the TSU became significantly more contaminated during the course of the test. Because the TSU was bagged (except for the bottom of the bag which was taped to the attachment fixture in the vibration cell), the contamination could not have come from the vibration cell. It is deduced that the increase in contamination levels on the mirrors is a result of particle redistribution within and around the COA. In essence, the TSU COA was the source of contamination for itself. Unfortunately, because of TSU schedule constraints, some contamination control measures could not be implemented. For example, the FIRAS was not disassembled, cleaned, and reassembled in a clean room as originally planned; it was assembled 'dirty', and then cleaned as a completely assembled instrument, which is considered a substantially less effective cleaning method. Last minute drilling operations on the COA had to be performed in the COA clean room, and although measures were taken to clean-up any generated contamination, it is possible that some particulate matter was missed.

Particle redistribution on relatively "clean" hardware does occur. The result is further contamination of virtually all surfaces. The TSU COA vibration test witness mirror results presented in this report show that, on 9 out of 12 mirrors, contamination levels after the vibration test exceed the overall COA cleanliness requirement (level 300). And, specifically the DIRBE primary mirror, which has a cleanliness requirement of level 100, showed unacceptable increases in contamination (level 800 and level 1000 on the two witness mirrors located on the dummy primary in the TSU). Considering the BRDF data presented, one of the DIRBE primary witness mirrors had a 44% change in BRDF at 30 degrees, which falls close to the 50% requirement; and the other DIRBE primary witness mirror had a 77% change in BRDF, which exceeds the requirement.

## FUTURE WORK

Using witness mirrors and the scattering measurement technique as a means to monitor contamination has proven to be an effective and useful tool. This technique can be used to monitor contamination in a number of different scenarios. For example, monitoring of cleanrooms and particle fallout, or monitoring of surface cleanliness during assembly, integration, test, transport etc., could be accomplished using this technique.

Table II. OPTICAL MICROSCOPY EXAMINATION DATA

| Mirror # - | Location             | - Contamination features  |
|------------|----------------------|---|
| I          | FIRAS PICKOFF MIRROR | Small particles observed. No large particles or fibers.   |
| II         | FIRAS PICKOFF MIRROR | Very large fibers observed, (1758X264 um, 1055X55 um, 530X70 um). Sharp edge metal particles present, 130X60 um. Several particulates up to "100 um diam.           |
| III        | APCO                 | One large fiber (1385X176 um). Round particles up to "180 um diam. in central area. Small dust particles elsewhere.   |
| IV         | APCO                 | Large metal particles with golden appearance, approximately round (198X176 um, 176X99 um).  |
| V          | APCO                 | One elongated fiber (circa 2000 um), metal particles (285X110), dust.   |
| VI         | DIRBE PRIMARY        | Elongated fiber (770X33 um), smaller fibers, yellow-reddish particles (oxide like), 150 um max diam. Metal particles (probably Al). Several smaller dust particles. |
| VIII       | APCO                 | Dust particles observed (240X110 um max).   |
| X          | APCO                 | Large fiber (505X420 um). Dust particles, max diam. circa 110 um.   |
| XI         | COA SIDE PANEL       | Very elongated, folded fiber, 593X374 um. Round particulates up to circa 260 um.  |
| XII        | APCO                 | Fibers (530X310 um, 440X350 um). Possible ceramic-type particle with inclusions, 370X242 um.  |
| XIII       | DIRBE PRIMARY        | Metal splinter (possibly Al) 950X130 um. Small diameter dust particles.   |
| XV         | COA SIDE PANEL       | Dust particles observed on the whole surface.   |

## REFERENCES

- [1]- N.J.Pugel, "Cosmic Background Explorer Contamination Control Plan. Phase II", COBE-PL-732-1703-01, September 1984.
- [2]- MIL-STD 1246A, "Product Cleanliness Levels and Contamination Control Plan".
- [3]- ASTM Standard F24-65 (Reapproved 1983), "Measuring and Counting Particulate Contamination on Surfaces".
- [4]- P.A.Carosso and N.J.P.Carosso, "The Role of Scattering Distribution Functions in Spacecraft Contamination Control Practices", Appl.Opt., Vol 25, page 1230, 1986.

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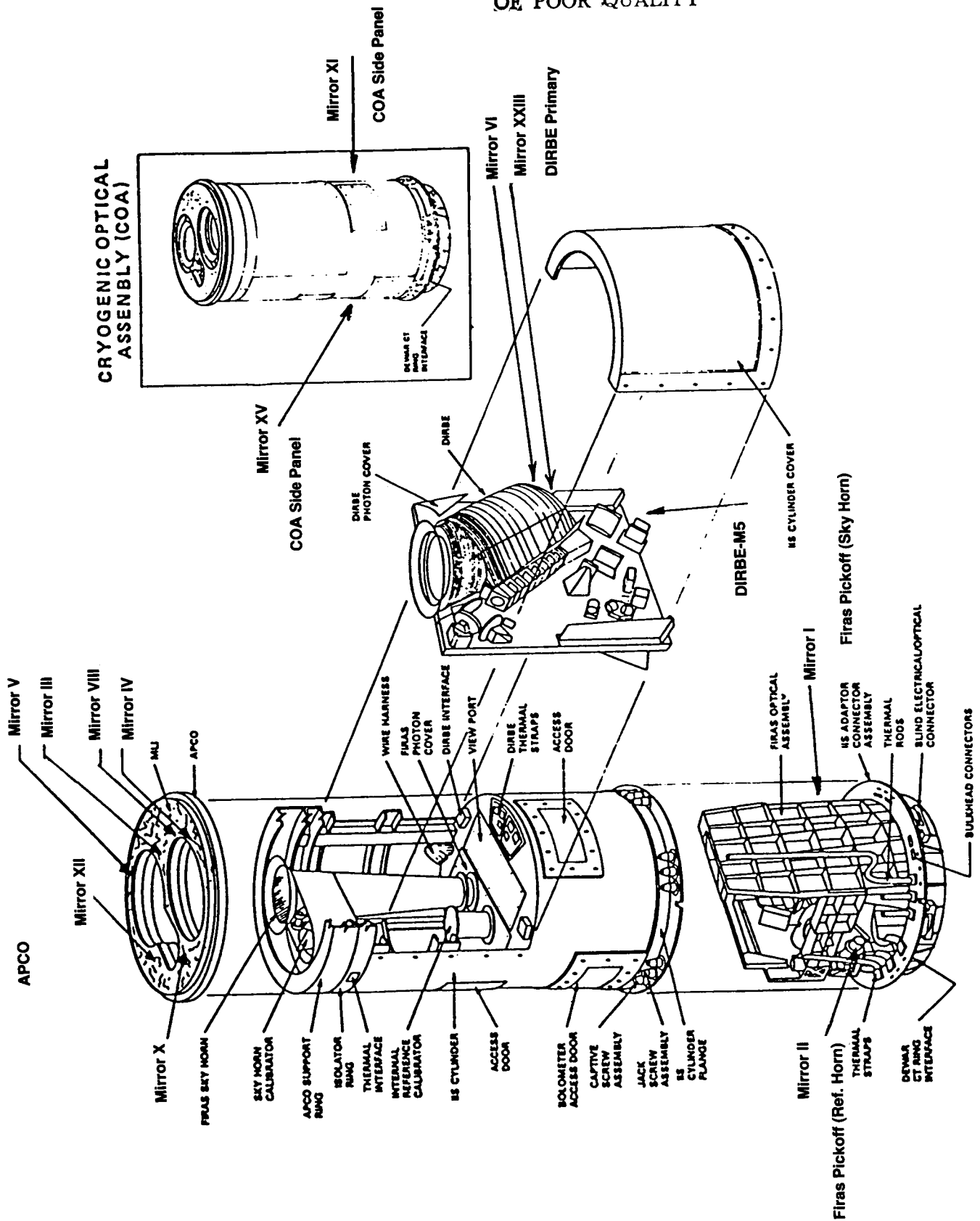


Figure 1. Witness mirrors location



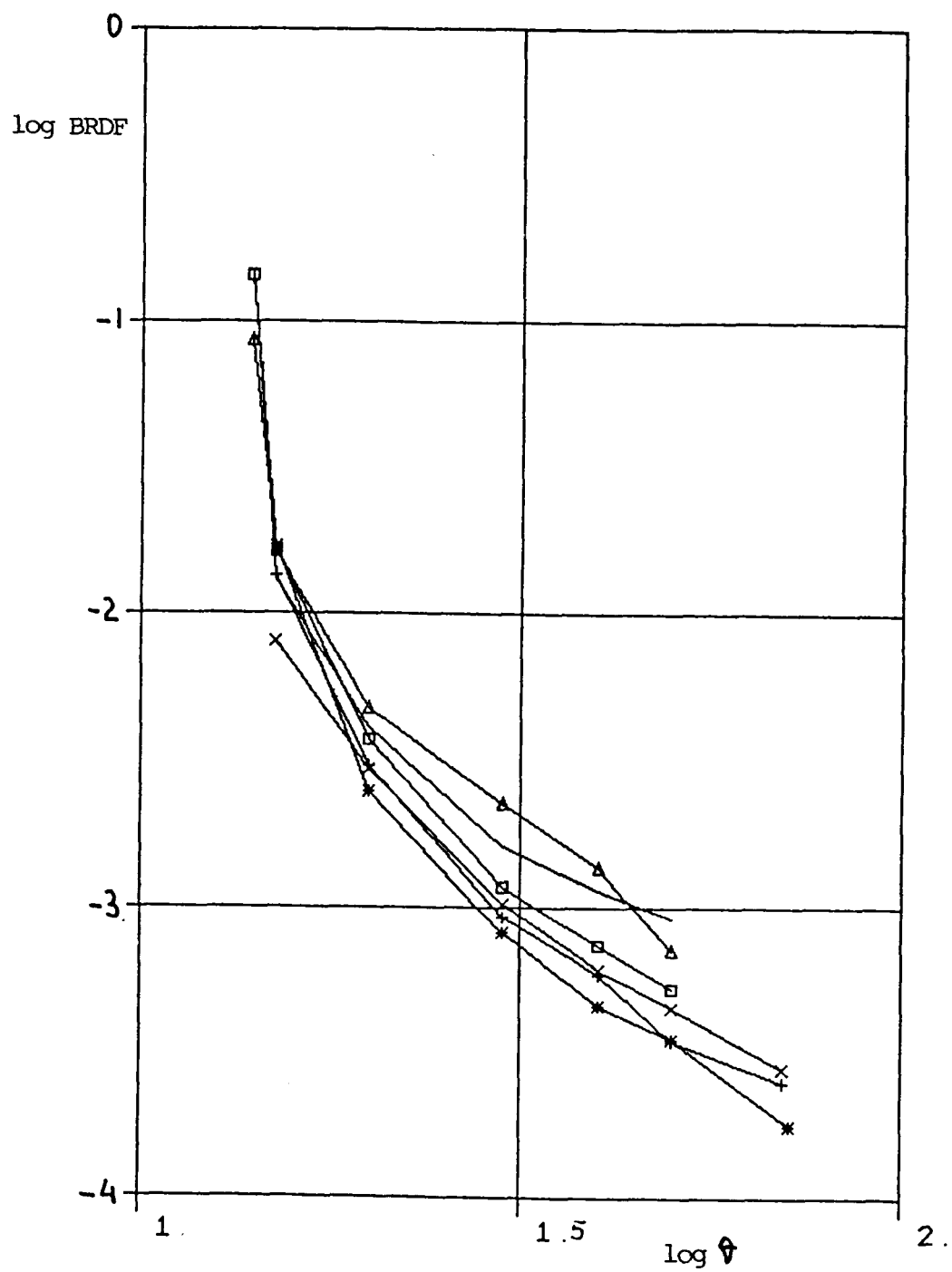


Figure 2. Mirror I

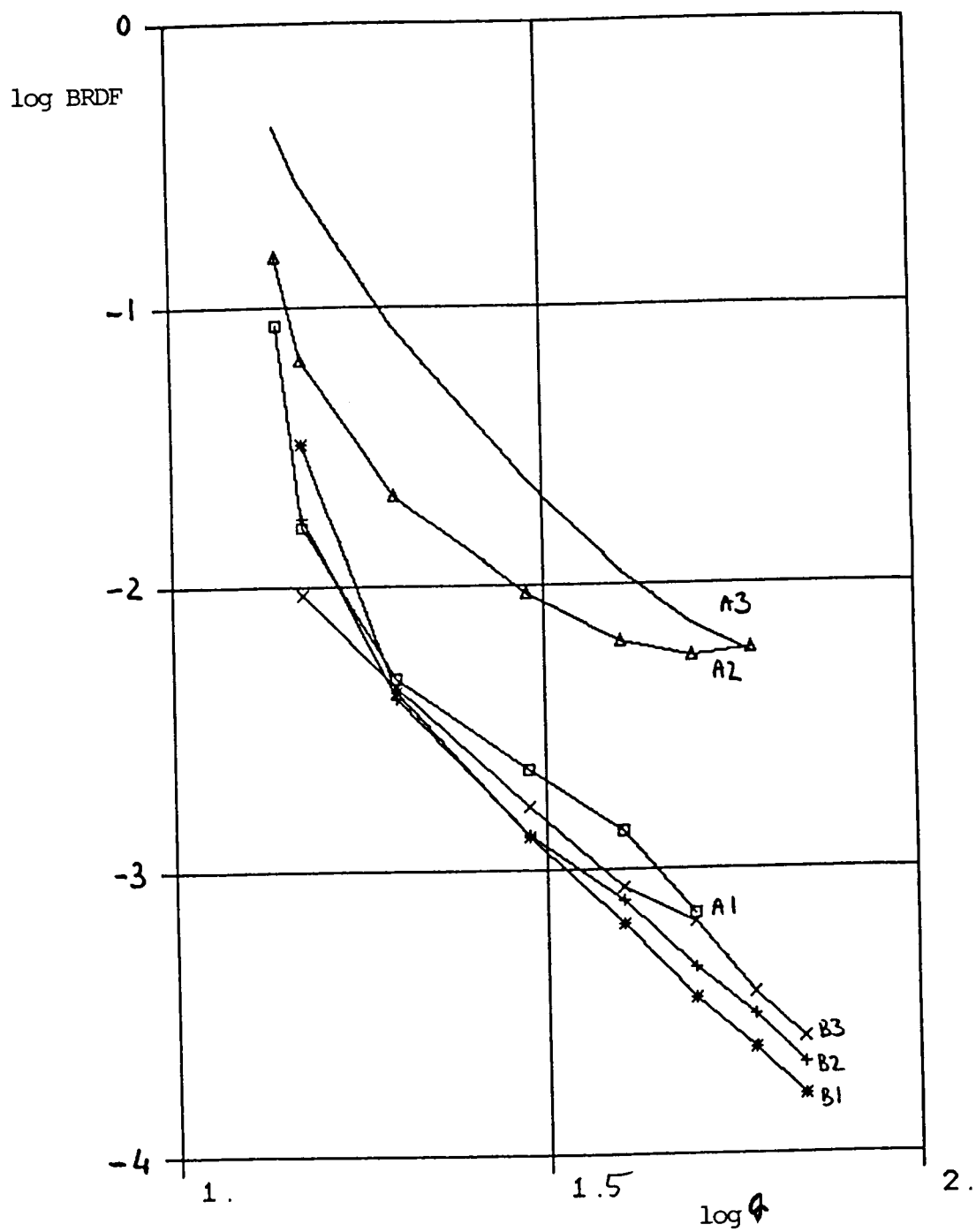


Figure 3. Mirror II

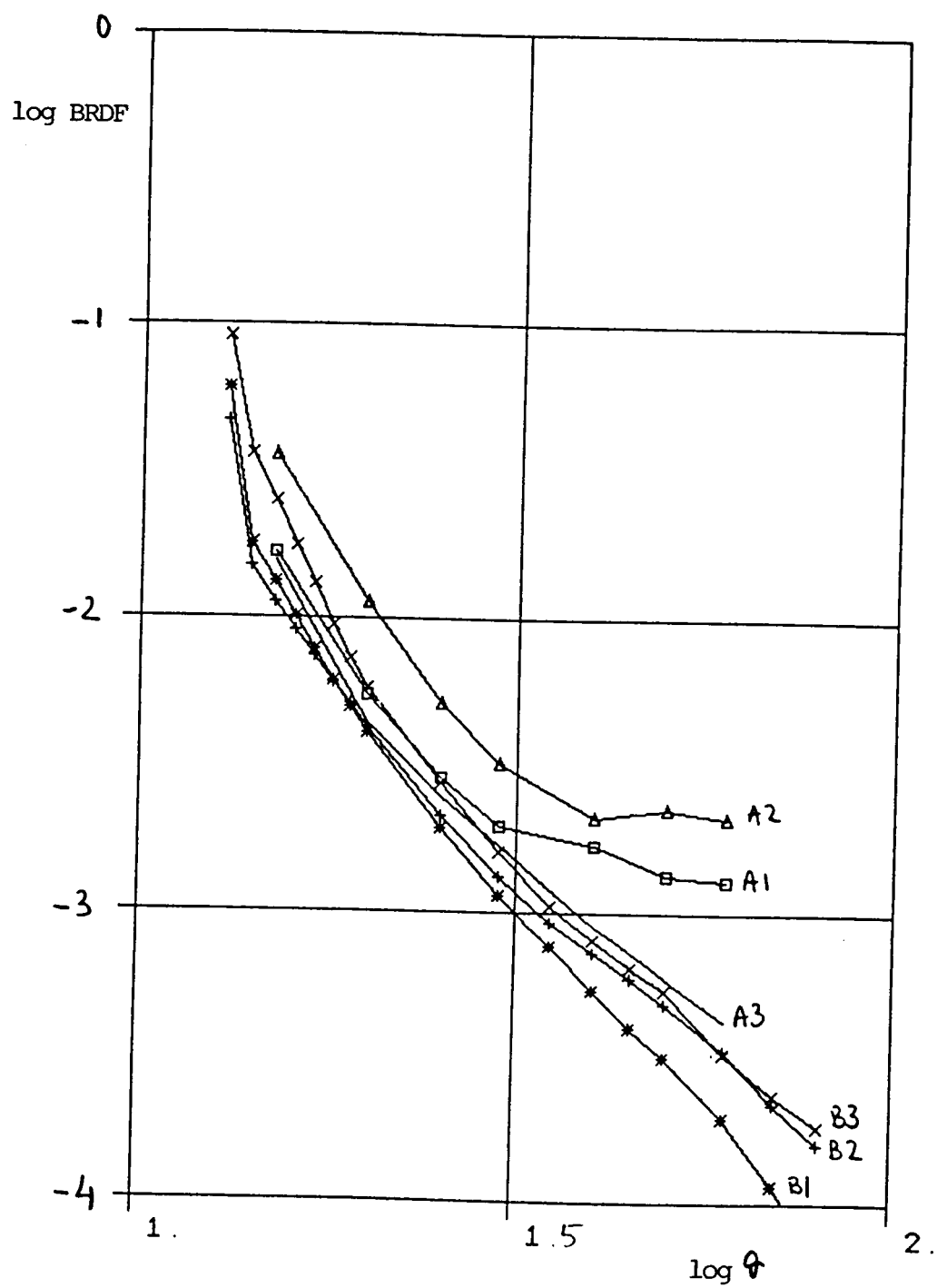


Figure 4. Mirror III

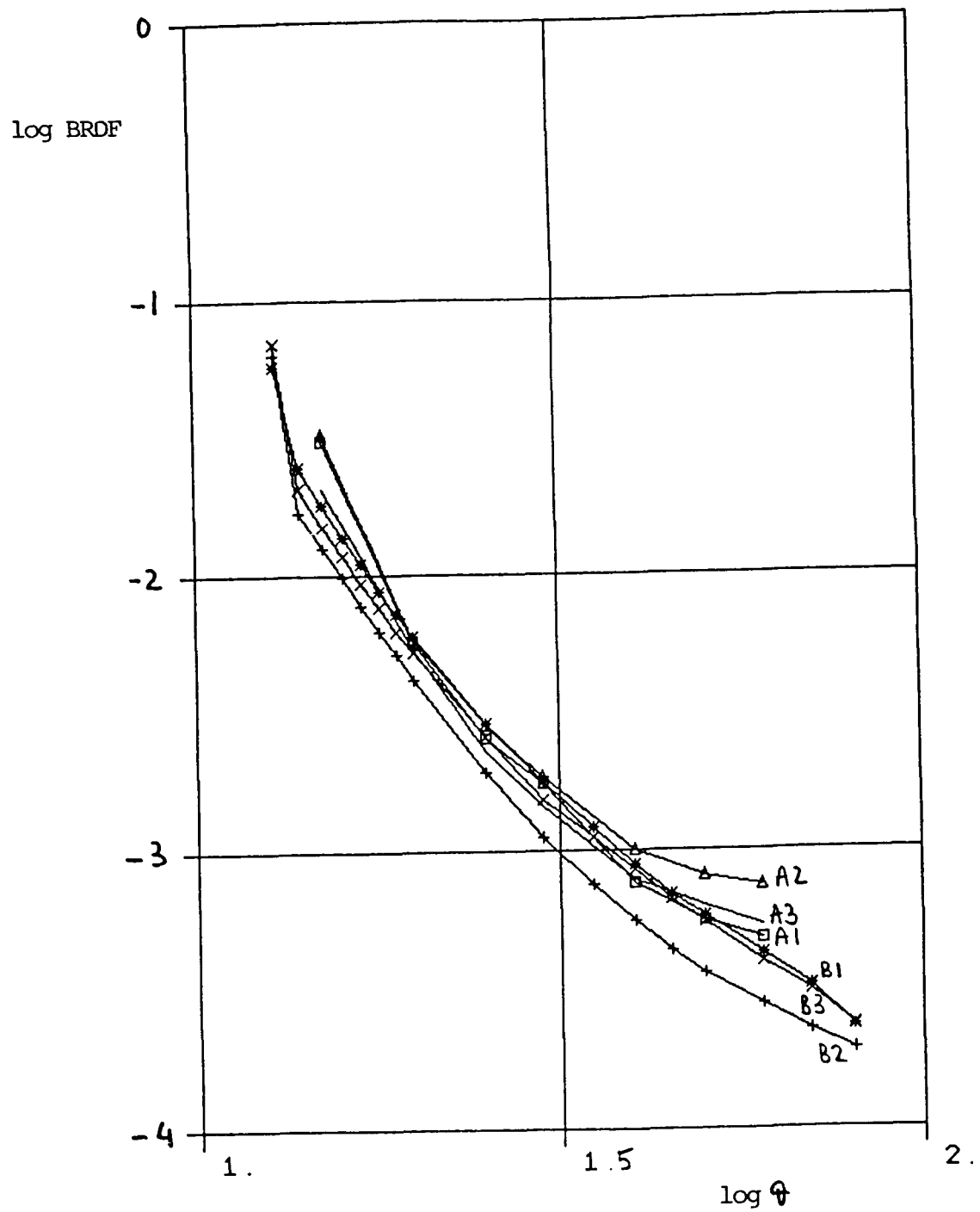


Figure 5. Mirror IV

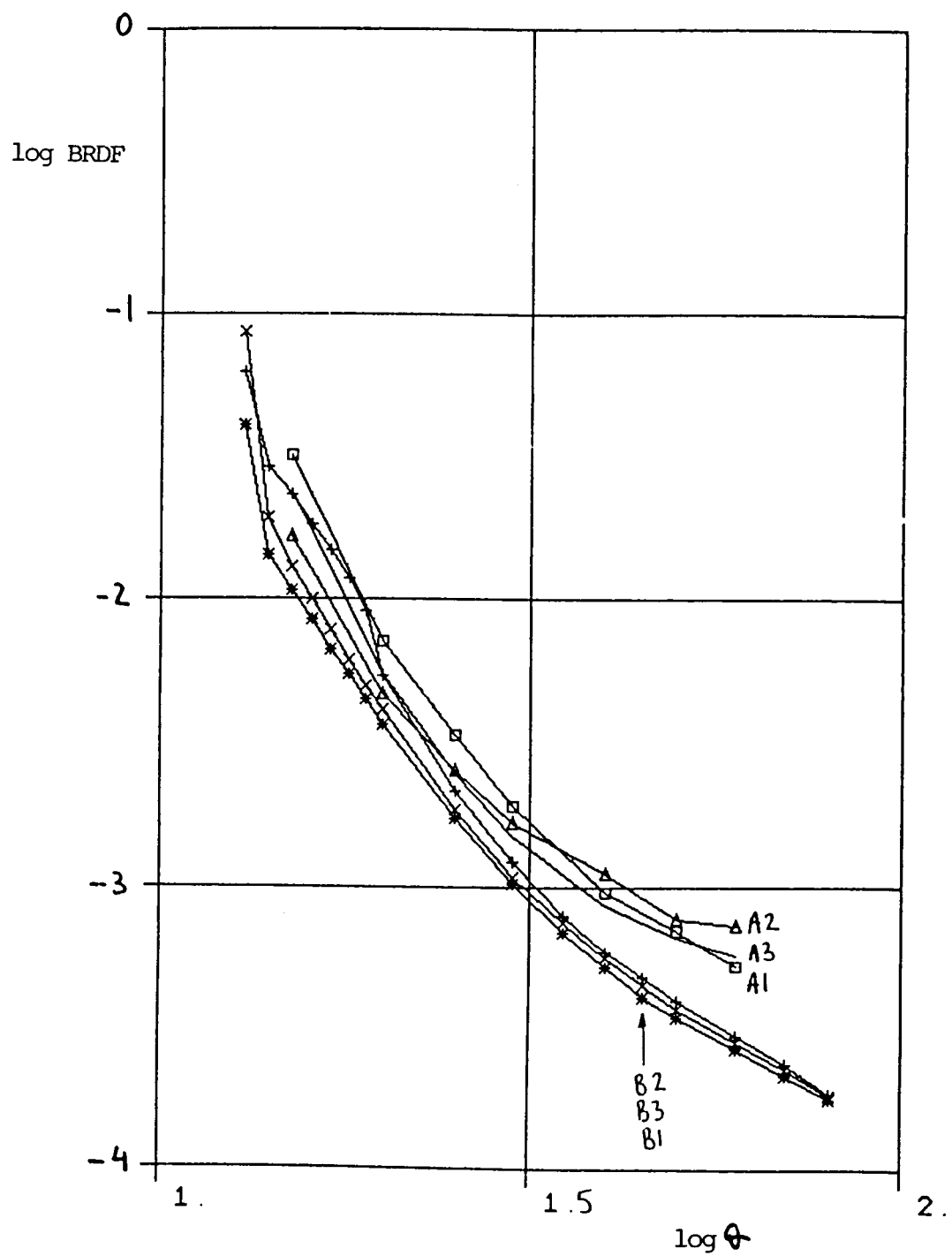


Figure 6. Mirror V

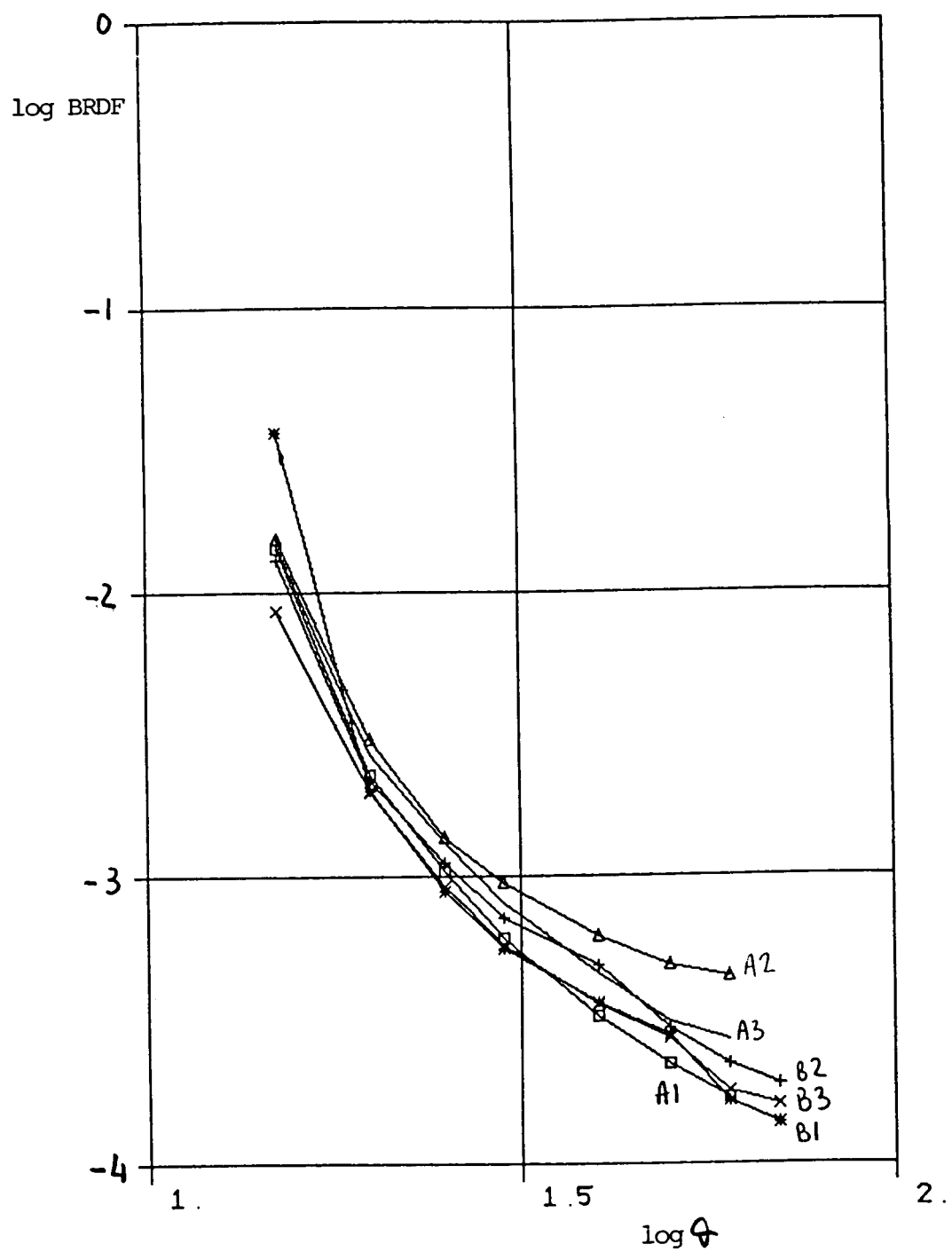


Figure 7. Mirror VI

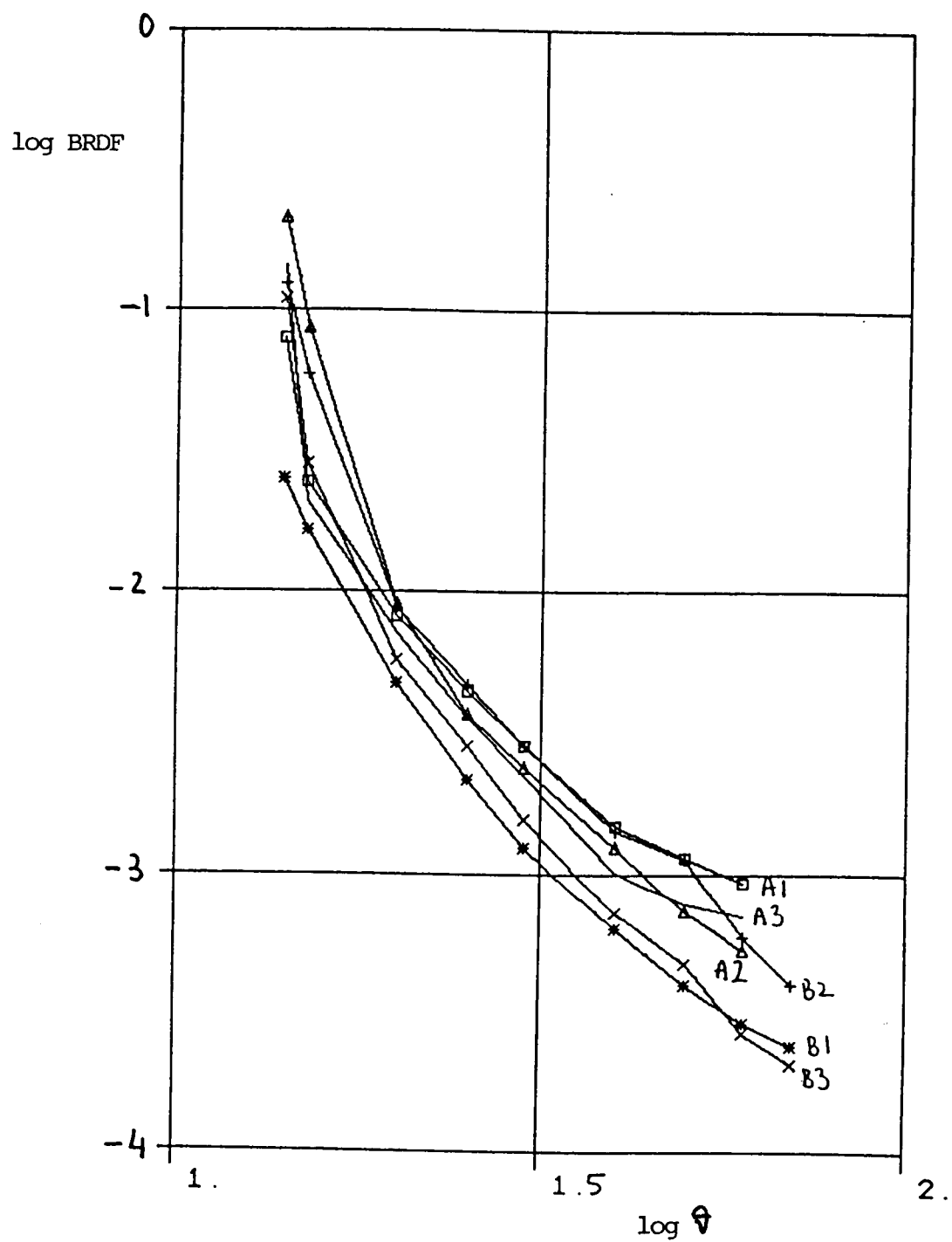


Figure 8. Mirror VIII

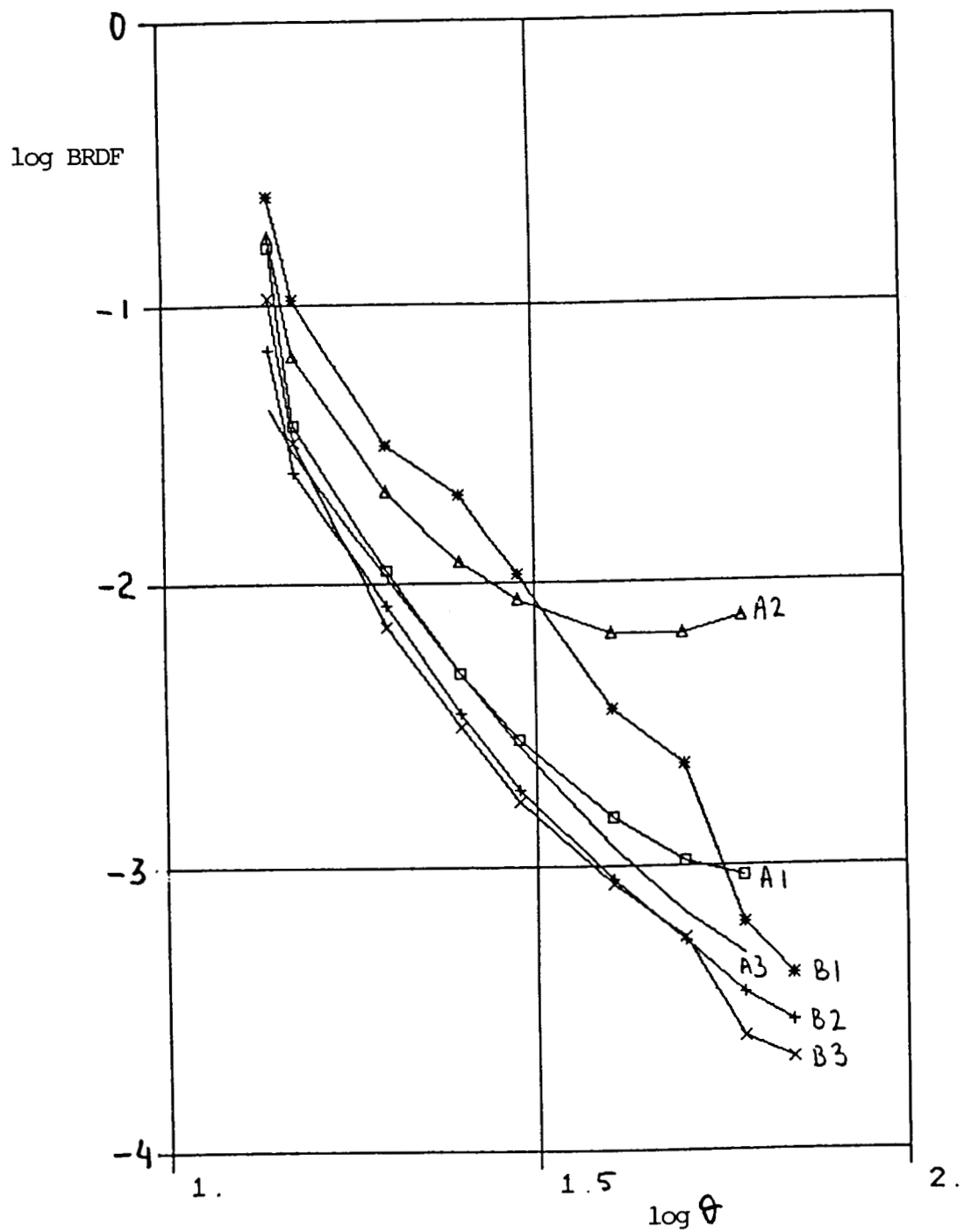


Figure 9. Mirror X



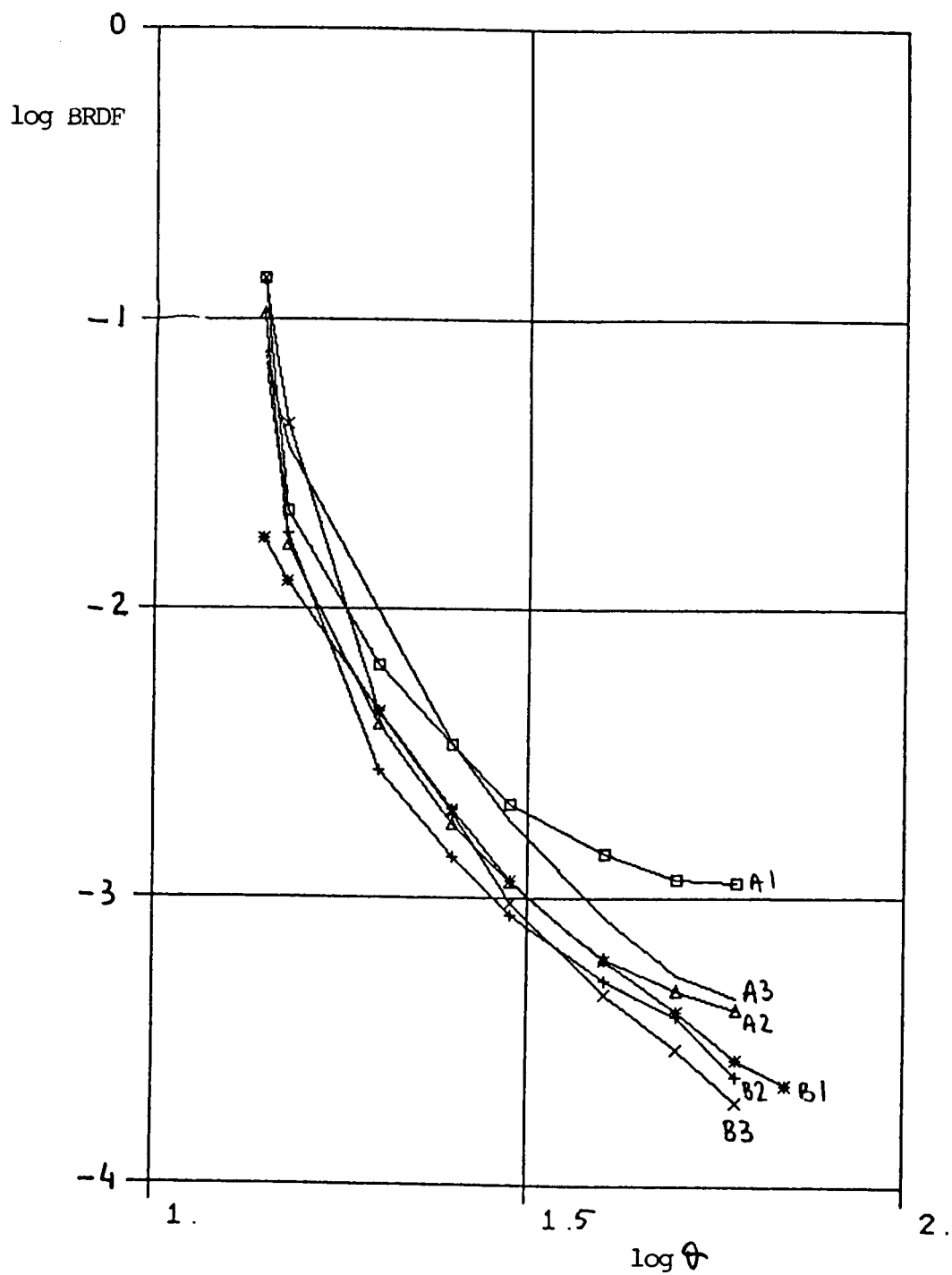


Figure 10. Mirror XI

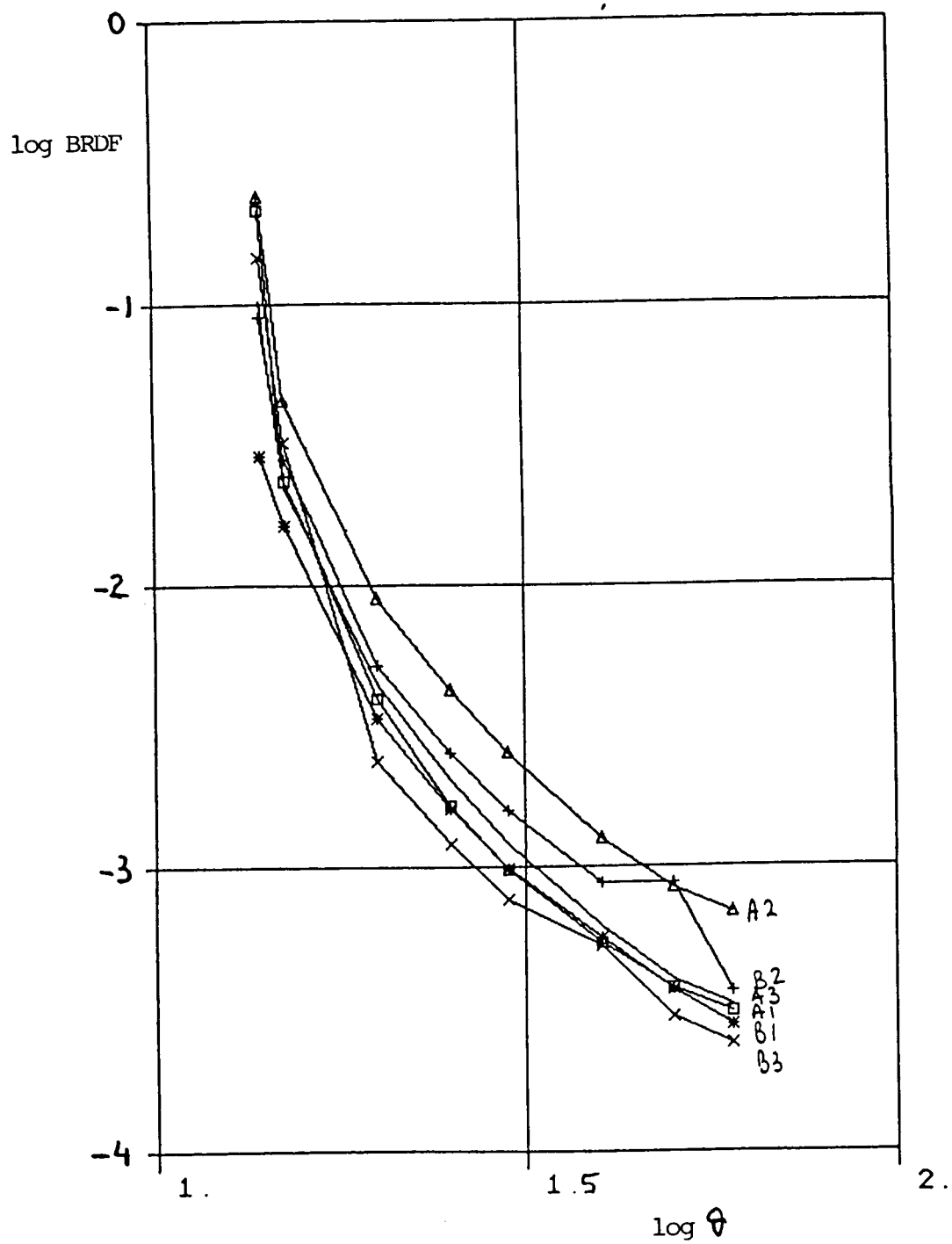


Figure 12. Mirror XIII

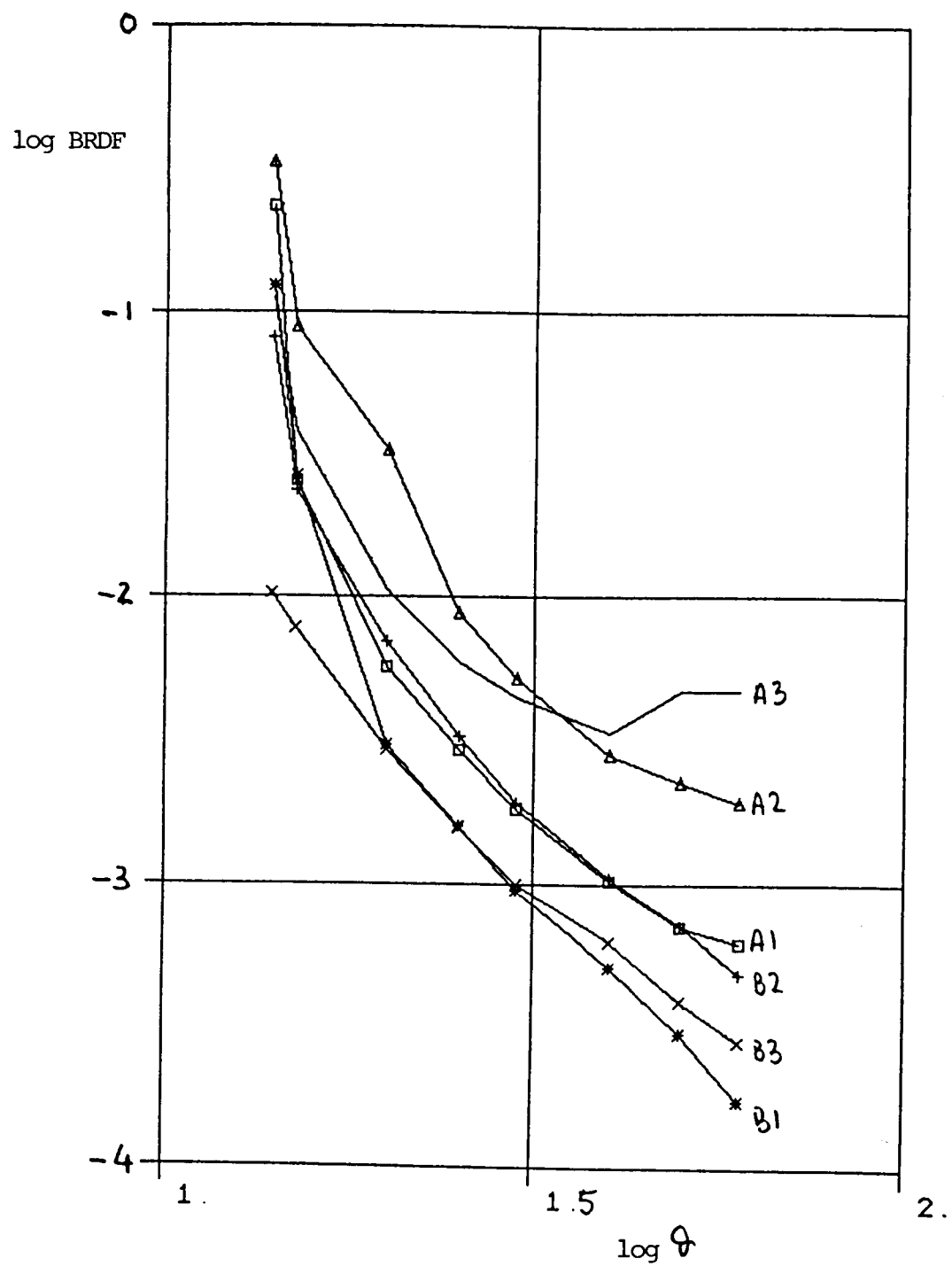


Figure 11. Mirror XII

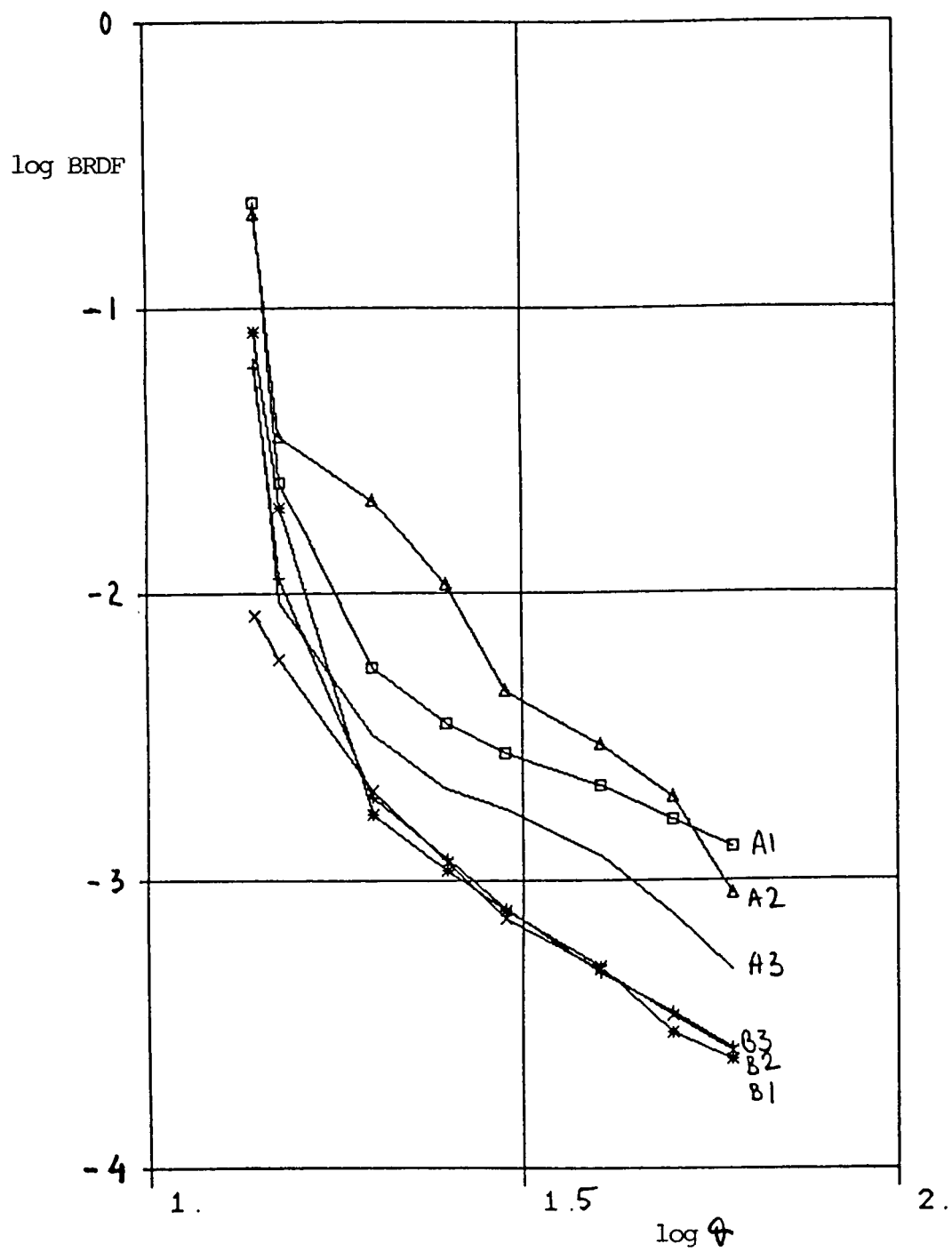


Figure 13. Mirror XV